

Multifunctional Structure-Battery Composites for Marine Applications

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Introduction: There is current interest in increasing the time-on-station endurance of unmanned underwater vehicles (UUVs) through the use of hybrid power systems consisting of fuel cells for cruise-mode and batteries for the sprint-mode portions of a mission. Today, most electric-powered UUVs use large batteries that are contained within the hull. In moving to hybrid power systems, significant hull space can be freed up for additional fuel-oxidizer or payload by relocating the battery cells into the UUV skin and other structural components.

In previous works, we have examined the use of multifunctional structure-power materials/components for increasing the available energy and/or decreasing weight in small-scale unmanned systems.¹ The present work focuses on the integration of high-energy lithium-ion (polymer) battery cells into fiber-reinforced polymer composite materials for application to larger-scale marine systems. The operational environment (i.e., seawater at depth) and large-scale structural and energy storage capacity requirements have posed new challenges in the multifunctional design process.

Galvanic corrosion and buoyancy are of fundamental concern, as are battery safety, charge/discharge control, and power bussing.

Laminates and Sandwiches: Traditional (unifunctional) marine composites are either fiber-reinforced polymer laminates or fiber-reinforced polymer face-sheets/foam core sandwich designs for enhanced bending performance and buoyancy. Both of these fundamental design configurations are addressed in this work. Laminates are used as skin, casing, and bulkheads, whereas sandwich composites are used in structural frame components and skins. The reinforcements are unidirectional carbon- and glass-fibers or woven cloth. The glass layers are used primarily on the exterior surfaces to provide electrical/galvanic isolation of the carbon layers. Core materials are closed-cell or syntactic foams depending upon the targeted depth rating.

Composite Testing: Three types of structure-battery (SB) composites have been designed, fabricated, and tested to demonstrate potential for underwater marine applications.² The first is an SB laminate with the cells “framed” within foam channels and then bonded between flat and conformal laminate layers. The second is an SB sandwich panel with cells embedded in a foam core. The third is a modular (easily removable) SB stiffener with cells framed in a foam channel bonded between laminate layers (Fig. 10).

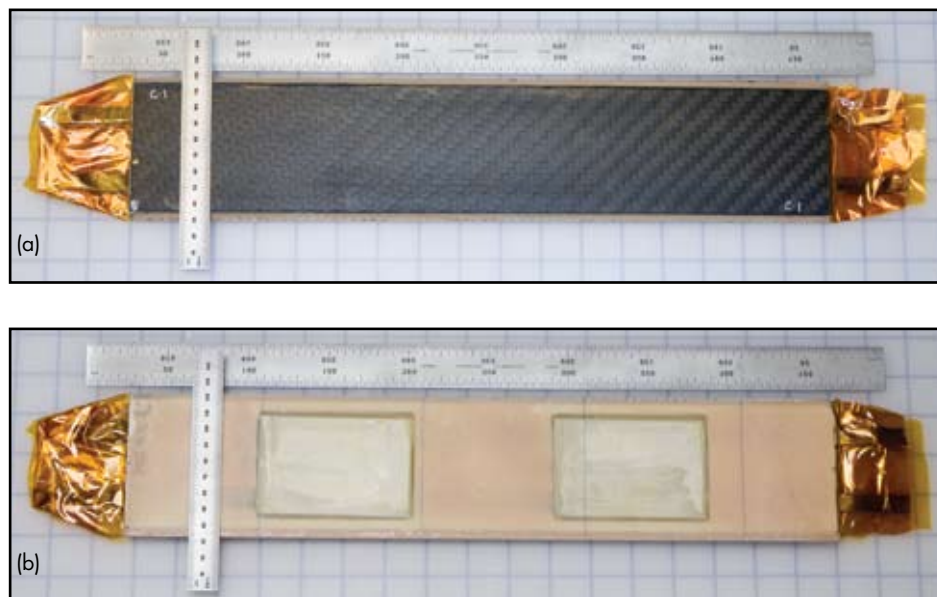


FIGURE 10

Modular structure-battery stiffener showing top (a) and bottom (b) views and the two embedded lithium cells. This SB stiffener can be (reversibly) attached to a structure to provide a significant increase in flexural stiffness and strength with energy storage capacity.

Unifunctional equivalents have also been fabricated for comparing mechanical performance. Performance objectives for the new SB composites include: 1) volumetric energy density of 50 Wh/L or greater; and similar or better: 2) structural properties, 3) buoyancy levels, and 4) dimensions relative to the unifunctional counterparts.

High-performance carbon- and glass-epoxy materials (prepregs and wet layup) from SP Gurit (Marine Composites Division) were used in the fabrication of all specimens.² The prepregs use the SE84LV epoxy resin (80 °C cure), and the wet layups use the Ampreg 22 resin (50 °C cure). The S-1800 SAN closed-cell foam was used for framing the battery cells and as a buoyant core material for the sandwich composites. Kokam USA rechargeable lithium ion cells (type SLPB 356495; 3.7 mm × 64 mm × 95 mm) were used and are nominally rated at 3.8 V and 2100 mAh capacity.

Results: Flexure testing to characterize mechanical bending stiffness, and Ragone testing, which measures energy storage capacity as a function of power discharge rate, were conducted to characterize the structural and electrical performance.³ Flexure testing demonstrated that the apparent bending stiffness of the multifunctional SB composites was equal to or better than that of the unifunctional counterparts. Volume normalized Ragone data (Fig. 11) show that the modular SB stiffener (without and with attached skin laminate) possesses the maximum energy density, followed by the SB sandwich and the SB laminate.

The results demonstrate the feasibility of integrating lithium-ion cells into structural composites to provide energy storage capability (50 Wh/L in this case) without degrading structural performance and buoyancy. Work is ongoing to characterize the flexural strength and the Ragone behavior under hydrostatic pressure. Critical issues for future investigation include 1) developing a fabrication process for co-curing of the composite materials with the battery cells without

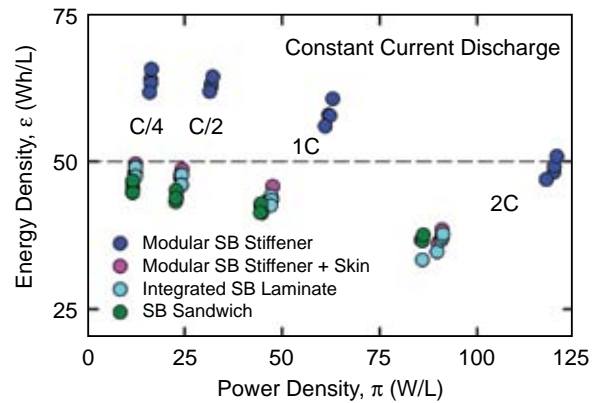


FIGURE 11

Ragone performance of the SB composites at four discharge rates. The fabricated specimens were slightly thicker than planned, which accounts for the slight underperformance (<50 Wh/L) of the integrated and sandwich SB composites.

degradation of energy storage capacity, and 2) improving the electrical safety and power connections through integrated battery management circuitry and multifunctional use of the carbon-epoxy layers for power bussing.

[Sponsored by ONR and NRL]

References

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